FINAL ENGINEERING REPORT
(THEORETICAL AND EXPERIMENTAL STUDIES OF
ANTENNAS FOR REFLECTOMETER APPLICATION)

The Ohio State University

ElectroScience Laboratory

(formerly Antenna Laboratory)
Department of Electrical Engineering
Columbus, Ohio 43212

Final Engineering Report 2143-6
10 April 1968

Grant Number NGR-36-008-048

National Aeronautics and Space Administration
Office of Grants and Research Contracts
Washington, D.C. 20546

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Government has the right to reproduce, use, and distribute this report for governmental purposes in accordance with the contract under which the report was produced. To protect the proprietary interests of the contractor and to avoid jeopardy of its obligations to the Government, the report may not be released for non-governmental use such as might constitute general publication without the express prior consent of The Ohio State University Research Foundation.

REPORT 2143-6

REPORT
by
THE OHIO STATE UNIVERSITY ELECTROSCIENCE LABORATORY
(FORMERLY THE ANTENNA LABORATORY)
COLUMBUS, OHIO 43212

Sponsor	National Aeronautics and Space Administration Washington, D.C., 20546
Grant No.	NGR-36-008-048
Investigation of	Theoretical and Experimental Studies of Antennas for Reflectometer Application
Subject of Report	Final Engineering Report 1 December 1965 - 29 February 1968
Submitted by	ElectroScience Laboratory (Formerly Antenna Laboratory) Department of Electrical Engineering
Date	10 April 1968

ABSTRACT

The accomplishments of a research program on theoretical and experimental studies of antennas for reflectometer application are summarized. Three basic areas were investigated toward achieving improved reflectometer design. The reflection coefficient of a parallel-plate waveguide illuminating a conducting sheet was analyzed as a function of the distance to the reflecting sheet. The influence of conducting flaps attached at antenna apertures was investigated both theoretically and experimentally and has been shown to yield considerable reduction in backscatter and hence less oscillatory response in the reflectometer. The effect of dielectric media on the aperture admittance of circular waveguides was also analyzed.

CONTENTS

INTRODUCTION

Current advances in space exploration and technology has provided a need for better understanding of space-craft antenna problems. An important phenomena is communications blackout during reentry due to plasma formation around the spacecraft. Considerable efforts have been devoted by several different approaches toward resolving this problem. One commonly used method of plasma diagnosis is through a vehicle mounted reflectometer system to measure the plasma standoff distance. Previously, the antennas for microwave reflectometers have been designed on the basis of their free space radiation characteristics, thus ignoring the interaction between the reentry plasma and the reflectometer antenna along with the surrounding surface of the vehicle. This procedure of using reflectometer antenna designs based on free-space characteristics has been necessary because of the lack of knowledge concerning these interactions.

The objective of this program has been to conduct research leading to improved reflectometer antenna designs. For this purpose, a study has been made of the interactions which occur between a reentry vehicle and its surrounding plasma sheath, and specific means for improving reflectometer antenna designs have been investigated.

REFLECTOMETER ANTENNA DESIGN INVESTIGATION

Throughout most of this program, research has been conducted to analyze the vehicle-plasma interactions by modeling the plasma with a reflecting sheet to simulate the critical boundary of the plasma. This technique utilizes, on the theoretical level, the approach used by NASA/ Langley in laboratory measurements of this type of interaction and should therefore allow good comparison between theory and experiment. The peculiar results obtained from these NASA measurements pointed to a need for better understanding of the interactions and had led to the sponsorship of this research program. In these measurements the reflection coefficient of the antenna was found to oscillate greatly in magnitude as a function of spacing to the reflecting sheet. For satisfactory reflectometer performance, it is desirable to achieve a monotone variation in reflection coefficient as a function of sheet spacing. It was this reflectometer problem of achieving monotone performance that provided the basis for this program.

A. Parallel-Plate Waveguide Illuminating a Conducting Sheet

Under this program several analyses have been developed for the reflection coefficient of a TEM waveguide radiating toward a reflecting sheet. These analyses apply for various waveguide geometries in which the waveguide walls are formed by conducting wedges having various angles.

Values of wedge angles for the 0°-75° case and the 90° case are treated in a technical report issued under this grant[1]; values in the 75° to 89° region are treated in a second such report.[2] Previous results were available only for a wedge angle equal to 90°.

The geometry for these analyses is shown in Fig. 1, and representative results obtained are given in Figs. 2 and 3. In Fig. 2 a comparison is given of the results computed by two different methods for a wedge angle of 75°; this wedge angle value corresponds to a point of mutual validity for both methods. The significant dependence of reflection coefficient on wedge angle value is shown in Fig. 3. It is seen that large variations or oscillations occur in the reflection coefficient as a function of sheet spacing, particularly for wedge angles near 90°.

These analyses have led to insight into the reflectometer problem. The results reveal that for wedge angles in the region of about 70°-90° the adjacent structure or ground plane of the guide causes large multiple reflections between the adjacent structure and the conducting sheet. This results in the large oscillations in the reflection coefficient which are detrimental to good performance as a reflectometer antenna. Thus, these analyses demonstrate the significance of the ground plane structure (or adjacent surface of a vehicle on which such an antenna might be mounted) in this application. In fact, these analyses indicate that this type of behavior would be expected for most types of waveguides and horns mounted in a ground plane. The conclusion of this theoretical investigation therefore was that the backscatter from the reflectometer antenna and its

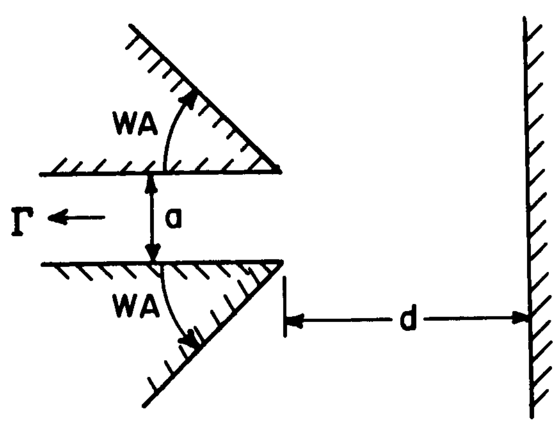

Fig. 1. Symmetric parallel-plate guide radiating into reflecting sheet.

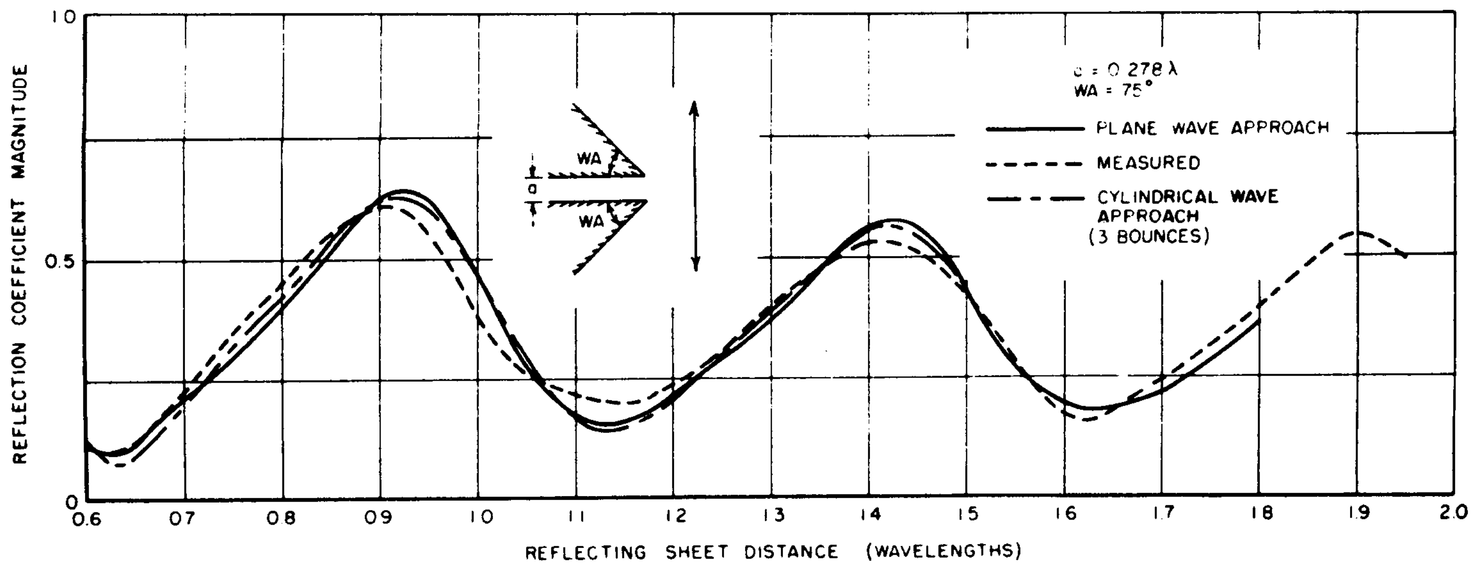

Fig. 2. Comparison of plane wave approach with cylindrical wave approach (the large wedge angle case) and measurement.

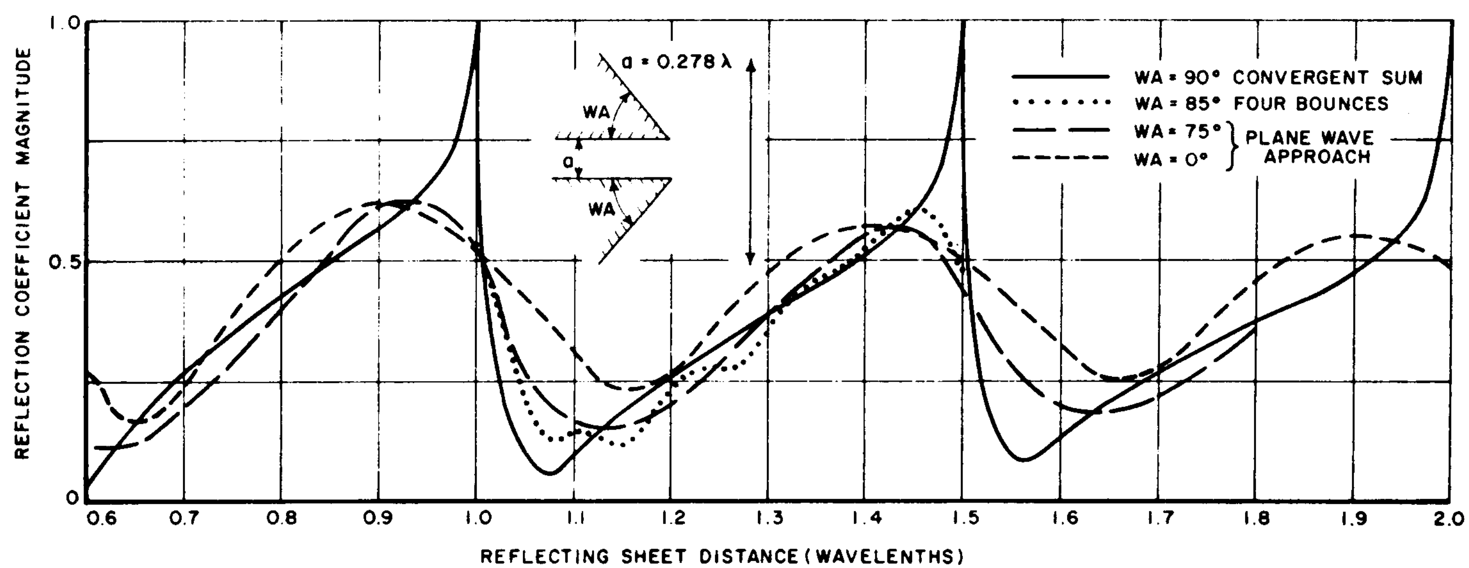

Fig. 3. Reflection coefficient magnitude as a function of wedge angle.

surrounding surface should be minimized in order to achieve the near monotone reflection characteristic needed for practical reflectometer performance.

B. Improvement in Reflectometer Design by Conducting Flaps

In view of the need to achieve monotone reflection, an experimental investigation was initiated to determine methods of minimizing the backscatter from reflectometer antennas. One of the most promising modifications which was discovered is the use of small conducting flaps. These flaps which are mounted at the edges of the aperture create a reflection which tends to reduce the backscatter from the reflectometer antenna. In practical applications the flaps would be embedded in the ablative layer or in the dielectric cover over the antenna aperture. Measurements were made which demonstrate that backscatter from small pyramidal horns can be reduced by the use of flaps. However, experimental reduction of the backscatter for antennas mounted in ground planes was not very successful. For results to be significant to the reflectometer problem, backscatter reduction must be achieved with a ground plane, which would simulate the surrounding vehicle surface.

Since flap geometries were based on experimental "cut-and-try" methods, a theoretical means of predicting good flap design was needed. In view of this, an analysis of the influence of conducting flaps on the reflection coefficient of a TE_{01} ground-plane-mounted parallel-plate waveguide illuminating a conducting sheet was undertaken.[3] The backscatter from the guide structure with the flaps projecting from the aperture was shown theoretically to depend on the length of the flaps. Calculated results also show that considerable reduction in backscatter can be achieved with optimum flap lengths. The reflection coefficient thus obtained from guide geometries with optimum length flaps at the aperture show drastic reductions in oscillation over the cases employing non-optimal flap lengths and especially the guide without flaps (as can be seen in Fig. 4).

C. Admittance of Circular Waveguides Radiating into Dielectric Media

Another area of research has been the effect of dielectric media on the aperture admittance of circular waveguides. The admittance of a circular waveguide aperture in a ground plane covered by a homogeneous dielectric slab medium has been analyzed for the TE_{11} mode. The Fourier transform method was used in this analysis. The analysis closely follows that for the rectangular waveguide case.[4,5] The resulting equations have been programmed on the IBM 7094 computer and admittance data for both lossy and lossless homogeneous slabs have been obtained.[6] Data for the case

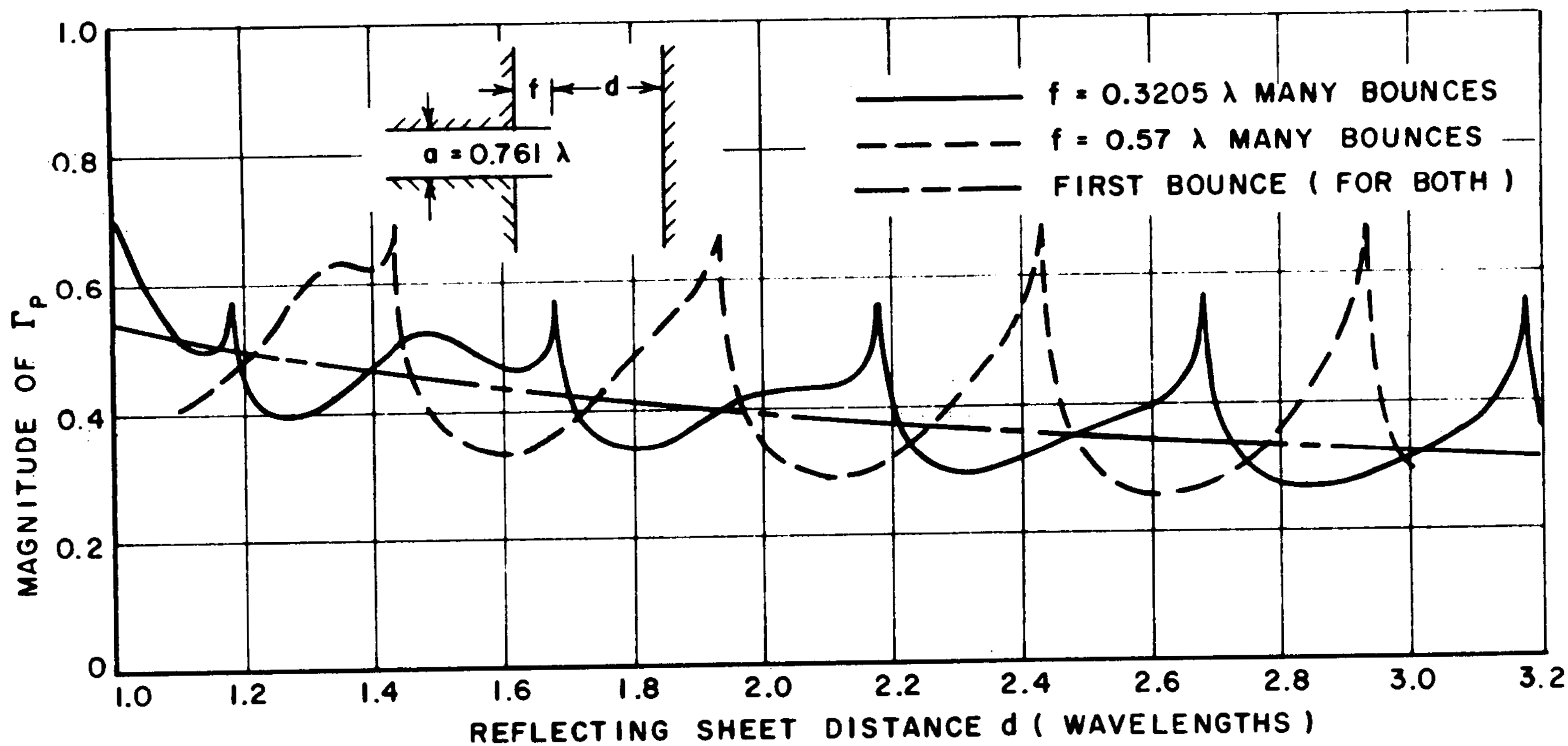

Fig. 4. The reflection coefficient magnitude for guides with flaps.

in which only free space is present outside the aperture are in good agreement with results obtained by Bailey, et.al.[7]

CONCLUSIONS

Research has been accomplished toward improved design of reflectometer antennas for plasma diagnostics. Toward this end, the reflection coefficient of a parallel-plate waveguide illuminating a conducting sheet was analyzed to gain insight into the oscillatory behavior of the reflection coefficient as a function of the distance to the reflecting sheet. In order to measure plasma standoff distance, however, a monotone response is desired. The above analysis indicated that this could be achieved by minimizing the backscatter from the waveguide. The introduction of conducting flaps mounted at the antenna aperture was thus employed and has since given considerable reduction in the oscillations of the reflection coefficient. The effect of dielectric media on the aperture admittance of circular waveguides was also analyzed.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several extensions of this research would be desirable for achieving best reflectometer designs. The simple planar flaps already analyzed have shown considerable promise in achieving the optimal monotone response. The basic theoretical approach used in that problem can be easily applied to analyze other flap geometries and reflecting devices. For example, another type of reflecting structure would incorporate a slot or series of corrugations adjacent to the antenna aperture. These results would give the design data necessary for the determination of the best reflectometer antenna configurations.

Another area of useful application is the calculation of the performance of conical horns. It appears that the analyses developed under this program can be extended to other antenna types, such as the conical horn, which are also useful as antennas on reentering vehicles and which, once these data are available, might be suitable for reflectometer applications.

The results achieved under this research program may also have application in other areas. For example, the reduction in backscatter due to conducting flaps might be employed in minimizing radar echo areas or in the reduction of coupling between slot antennas.

REFERENCES

1. Tsai, L.L., "The Reflection Coefficient of a TEM Mode Parallel-Plate Waveguide Illuminating a Perfectly Reflecting Sheet," Report 2143-1, 25 August 1966, ElectroScience Laboratory (formerly Antenna Laboratory), The Ohio State University Research Foundation; prepared under Grant NGR-36-008-048 with National Aeronautics and Space Administration.

2. Burnside, W.D., L.L. Tsai, and R.C. Rudduck, "The Reflection Coefficient of a TEM Mode Parallel-Plate Waveguide Illuminating a Conducting Sheet: the Large Wedge Angle Case, Report 2143-2, 2 February 1968, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Grant NGR-36-008-048 with National Aeronautics and Space Administration.

3. Tsai, L.L., and Rudduck, R.C., "The Influence of Conducting Flaps on the Reflection Coefficient of a Parallel-Plate Waveguide Illuminating a Conducting Sheet," Report 2143-5, (ElectroScience Laboratory report in processing).

4. Rudduck, R.C., "The Admittance of a Rectangular Waveguide Aperture Covered by a Lossless Dielectric Slab," Report 1691-22, 15 May 1967, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Grant NsG-448 with National Aeronautics and Space Administration.

5. Croswell, W.F., Rudduck, R.C., and Hatcher, D.M., "The Admittance of a Rectangular Waveguide Radiating into a Dielectric Slab," IEEE Transactions on Antennas and Propagation, Vol. AP-15, No. 5, September 1967, pp. 627-633.

6. VanDoeren, R.E., "Input Admittance and Reflection Coefficient of a Circular Aperture in a Ground Plane Covered by a Homogeneous Dielectric or Plasma Slab," Report 2143-4, 2 February 1968, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Grant NGR-36-008-048 with National Aeronautics and Space Administration.

7. Bailey, M.C., et.al., "The Input Admittance of a Circular Waveguide Opening onto a Flat, Dielectric Covered Ground Plane," a paper submitted to Radio Science for publication.